Development of Wind Turbines Prototyping Software Under Matlab/Simulink® Through Undergraduate Student Projects

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M. E. H. Benbouzid, D. Diallo, Y. Amirat, H. Mangel and A. Mamoune

***Abstract*—Electrical Engineering and more particularly Power Engineering at the undergraduate level is facing a crisis at many French universities in terms of enrollment. One reason is the attraction of "newer" areas like computer engineering, which seem to excite the students more and pay higher starting salaries. In this difficult context, a significant educational investment is necessary to excite the students and entice them into Power Engineering. An area that students universally find interesting is alternate energy systems based on a renewable energy supply like wind. What is interesting with this area is that it includes the fundamental material that already exists in many energy conversion courses. Therefore, in this paper the authors present the development of a wind turbine prototyping software under Matlab/Simulink® through undergraduate student projects within the Electrical and Computer Engineering Professional Institute (IUP GEII) at Amiens, France [1]. This software was developed by a group of three students of the Institute third and final year. It was then used by another group of three students of the Institute second year to realize a wind energy system model.**

***Index Terms*—Renewable energies, wind energy systems, student projects, Matlab/Simulink®, simulation, realization.**

I. Introduction

THE fast development of the wind energy market as well as of the technology has large implications on research, education as well as on professionals working for electric utilities or the wind energy industry. It is important to mention that about 80% of the worldwide wind capacity is installed in only five countries: Germany, USA, Denmark, India and Spain. Hence, most of the wind energy knowledge is based in these countries. The use of wind energy technology, however, is fast spreading to other areas in the world. Hence, the available information must also be spread around the world [2]. Wind energy was the fastest growing energy technology in the 1990s, in terms of percentage of yearly growth of installed capacity per technology source.

The growth of wind energy, however, is not evenly distributed around the world. By the end of 1999, around 69% of the worldwide wind energy capacity was installed in Europe, a further 19% in North America and 10% in Asia and the Pacific. Between the end of 1995 and the end of 1999, around 75% of all new grid-connected wind turbines worldwide were installed in Europe [3].

Figure 1 shows the wind resources in Western Europe. The illustration shows that France has large wind resources, and more specifically, France appears to have the second largest wind energy potential in Europe, after the United Kingdom. According to certain estimates, the potential annual production is evaluated at 70 TWh on the land and more than 90 TWh for offshore sites located in an area along the coast, with a maximum width of 10 km and where the sea depth is less than 10 m [4].

This potential production of more than 160 TWh represents approximately 33% of the present electricity generation in France. Therefore and as illustrated by Fig. 2, for France a gap has to be filled. This will obviously lead to an improved job market for electrical engineers. Therefore, the wind energy revival market will have a large impact on electrical engineering education.

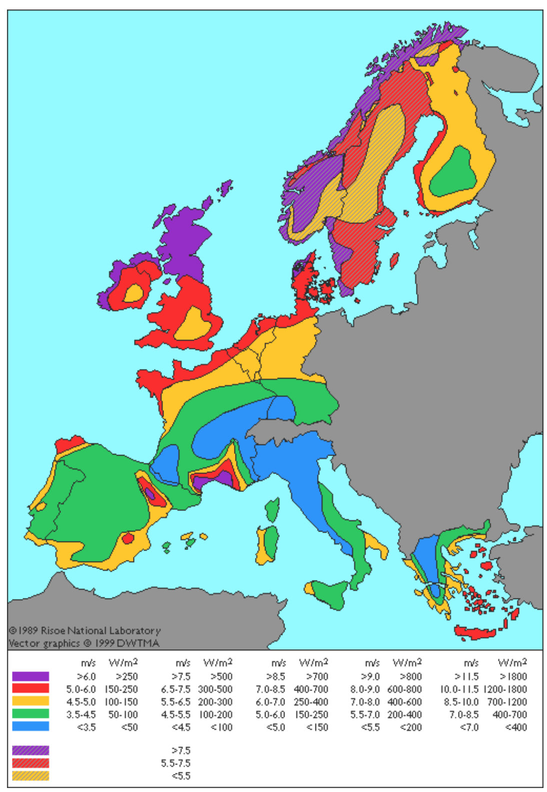

Fig. 1. Wind resources in Western Europe (according to RISOE, for the European Commission).

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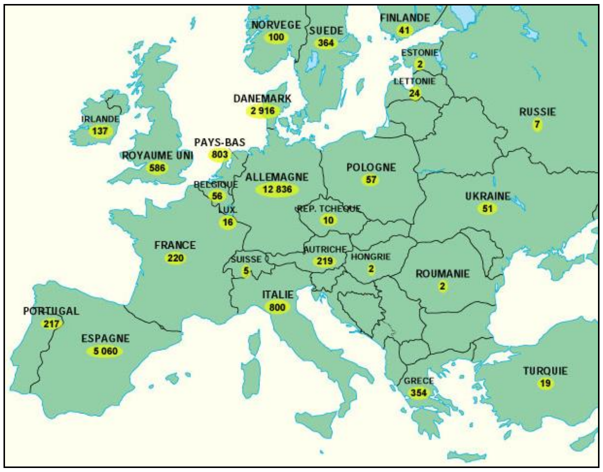


Fig. 2. Wind power in MW installed in Europe by end 2003 (according to European Association for Wind Energy).

As Electrical Engineering and more particularly Power Engineering at the undergraduate level is facing a crisis at many French universities in terms of enrollment, an educational investment is therefore necessary to excite the students and entice them into Power Engineering according to their high interest to environmental topics such as pollution prevention, pollution remediation, natural resource utilization, as well as global and local weather studies.

Therefore, introduction of renewable energy applications into electrical engineering should impacted not only students, but faculty and university community positively and promoted feasibility and adoption of more eco-friendly energy technologies [5-7]. Moreover, alternate energy systems based on a renewable energy supply like wind provide an excellent catalyst for teaching some of the Power Engineering principles. Indeed, wind energy area includes the fundamental material that already exists in many energy conversion courses.

In this paper, the authors present a first step toward the above global objective. Indeed, this first step is the introduction of renewable energies through undergraduate student projects because they were found as an excellent framework to train nontechnical skills essential for every engineer; and finally, it causes a clear motivation boost for the fresh Electrical Engineering students [8]. In the following is presented the development of a wind turbine prototyping software under Matlab/Simulink® through undergraduate student projects within the Electrical and Computer Engineering Professional Institute (IUP GEII) at Amiens, France. This software was developed by a group of three students of the Institute third and final year. It was then used by another group of three students of the Institute second year to realize a wind energy system model.

II. Wind Energy System Dimensioning

Wind energy system (Fig. 3) dimensioning is a complex problem since one is confronted to technological choices (generators, blades, etc.) and to environmental constraints (land, offshore, etc., Fig. 4). Computer Aided Dimensioning is therefore needed and should be helpful.

In this context, a first group of three students (Institute third and final year) was settled down to develop prototyping software for wind turbines.

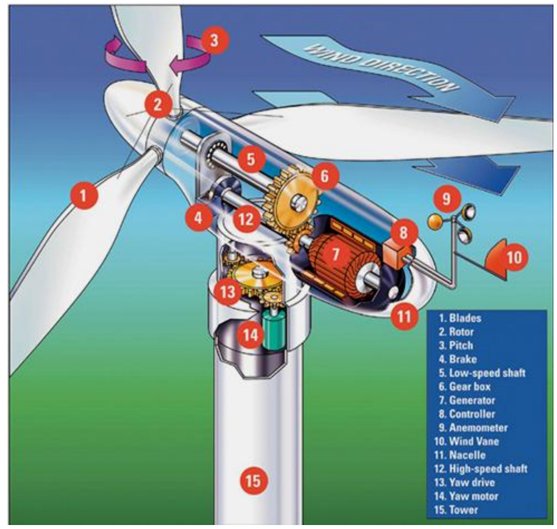


Fig. 3. Cutaway of a wind turbine nacelle.

Fig. 4. Wind farm types.

This software is not only intended for prototyping but will be used for simulation. Indeed, its purpose is to simulate the dynamical behavior and the electrical properties of a wind turbine. The modeling of the wind turbine should create a model as simple as possible from a mechanical point of view (according to the undergraduate student level), but capable of providing a good description of the electrical characteristics of a wind turbine. The wind turbine is characterized by the nondimensional curves of the power coefficient as a function of both tip speed ratio and the blade pitch angle. The tip speed ratio is the ratio of linear speed at the tip of blades to the speed of the wind [2].

III. The Software Presentation

In order to simulate the wind turbine as part of a distribution system, simple models have been developed and implemented in Matlab/Simulink® for each element. The wind turbine model consists of different component models: wind model, aerodynamic model, transmission model, and of the electrical components such as induction generator [9-11]. Figure 5 show the starting scheme for the software development.

A. Wind Turbine Model

The developed model is based on the steady-state power characteristics of the turbine.

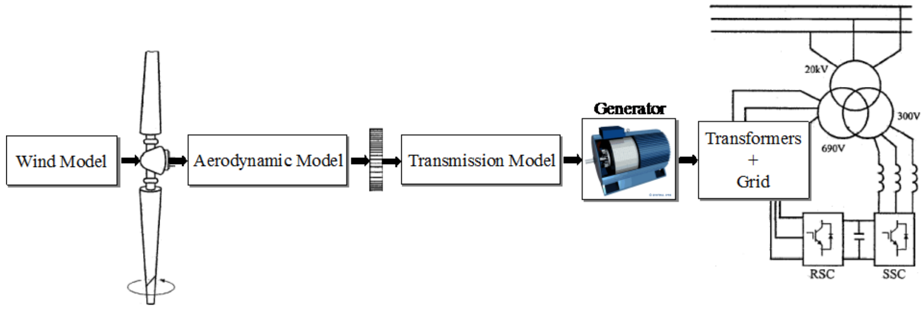


Fig. 5. Simplified scheme of wind turbine model.

The amount of power captured from a wind turbine is specific to each turbine and is governed by [11]

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \rho A v_w^3 \tag{1}$$

where P_m is the mechanical output power of the turbine, C_p is the turbine power coefficient (λ is the tip speed ratio and β is the blade pitch angle), ρ is the air density, A is the turbine swept area, and v_w is the wind speed. Note that the tip-speed ratio is defined as

$$\lambda = \frac{R\Omega}{v_w} \tag{2}$$

Where R is the turbine radius and Ω is its rotational speed.

The C_p-λ characteristics, for different values of the pitch angle β, are illustrated in Fig. 6. This figure indicates that there is one specific λ at which the turbine is most efficient. Figure 7 shows typical wind power versus turbine rotor speed curves for different wind speeds. For each wind speed, the maximum power point corresponds to only one value of the turbine speed. Unlike constant-speed control, a variable-speed control can adjust the speed of the turbine when the wind speed changes, then the system can operate at the peak of the curve.

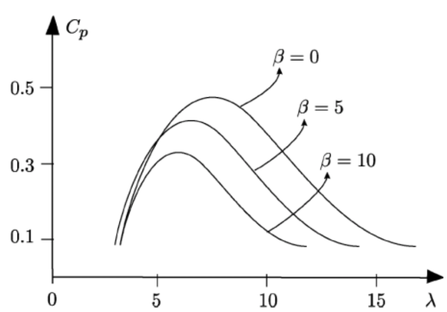


Fig. 6. C_p-λ characteristics, for different values of the pitch angle.

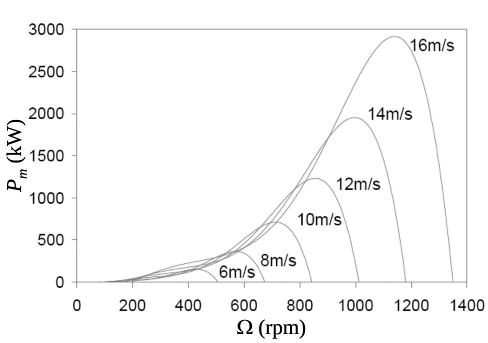


Fig. 7. Turbine output power characteristic.

The turbine mechanical output power is given by

$$P_m = T_m \Omega \tag{3}$$

where, T_m is the mechanical torque at the turbine side.

The wind turbine mechanical characteristics are described by the following equation where the turbine rotor friction is ignored).

$$T_m - T_g = J \frac{d\Omega}{dt} \tag{4}$$

where, T_g is the load and J is the turbine inertia moment.

B. Simulink Model

Figure 8 illustrates the model that has been implemented in Matlab/Simulink®. The wind turbine model, designed as a subsystem block in Simulink, is easily integrated into the entire wind power generation system along with the other components for simulation studies. This figure particularly highlights the basic prototyping components: Environment components, wind system data, wind simulation, site input power, wind system output power, and the generator [12].

C. Graphical User Interfaces (GUI) Development

A GUI is intended to create graphical interfaces leading to a simplified and user-friendly application. It is implemented using Matlab code and Simulink files. The obtained interfaces look like Microsoft-Windows ones so as to assist the software user. The GUI input data are the characteristics of the following components:

– *The wind system*. Mainly the rotor data (diameter, swept surface, blade number, speed) and the hub height (Fig. 9).

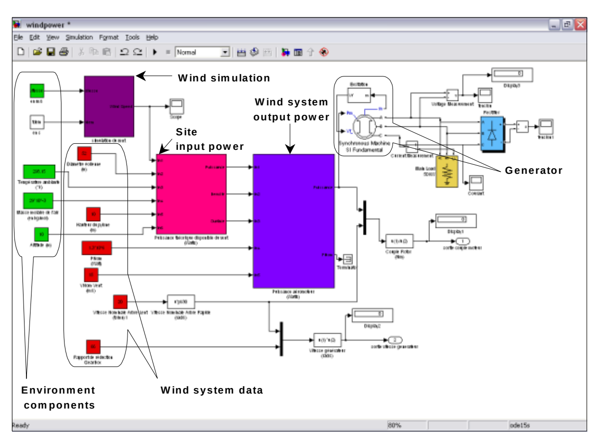


Fig. 8. Wind turbine simulation.

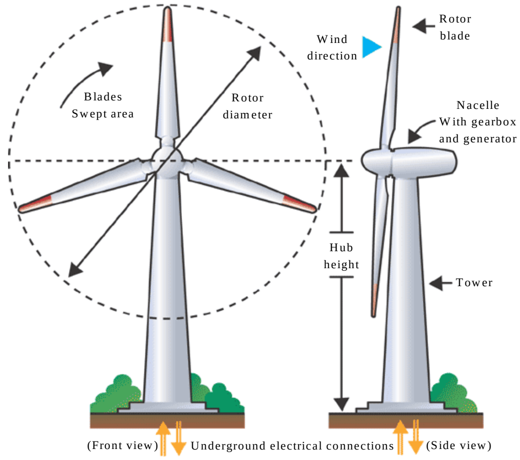


Fig. 9. Wind energy system schematic.

– *The generator*. Mainly the generator type, the output frequency, the output voltage and the rated power (eventually the maximum power) and as many data as it is possible to find.

– *The gearbox*. The gear ratio.

– *The environment*. The wind speed, the outside air temperature, the air molar mass, and the altitude.

The adopted software approach is to give the user two possible prototyping choices for its wind energy system. The first choice consists in prototyping the wind system using manufacturer data. For this case, a database of the main wind turbine manufacturers has been setup. The software can help to quickly evaluate the power produced by the selected wind system. The second proposed choice consists in prototyping the wind system using the user own characteristics. In both cases, once the characteristics entered, the wind system can be simulated in a separate window. This one represents the simulation environment and allows the graphical representation of different variable evolution (e.g. power versus speed, etc.).

Figure 10 illustrates the general menu of the developed software.

1) "Customized" Menu. This menu, as illustrated by Fig. 11, allows the user to choose its wind system characteristics. However, choices are bounded by coherent data. Indeed, some parameters are very different according to the wind system dimensions. For example, one could not consider a 2 MW wind turbine with 4 m diameter and a 500-rpm speed. Such a simulation could not be possible because modeling must be coherent with reality. Thus, two dimensioning types are proposed (small and big size wind systems). According to the user choice, different coherent values are available. It is also possible to adjust the environmental parameters for the simulation (Fig. 12): the wind speed, the outside air temperature and the altitude (default values are 15 m/sec, 20°C, 50 m).

2) "Manufacturer" Menu. This menu, as illustrated by Fig. 13, allows the user to choose the wind system manufacturer and its models. The user has, in this case, all the information concerning the selected wind system.

3) The Simulation Window. This window displays several information: the wind system characteristics and those that are calculated under Simulink (Fig. 14). It is also possible to visualize the adopted simulation model in the graphical menu. After simulation, the user will obtain the following information or results [2]:

Fig. 10. The general menu of the software.

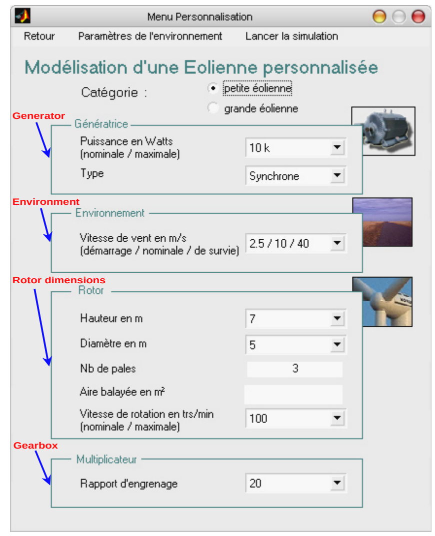


Fig. 11. The "customized" menu.

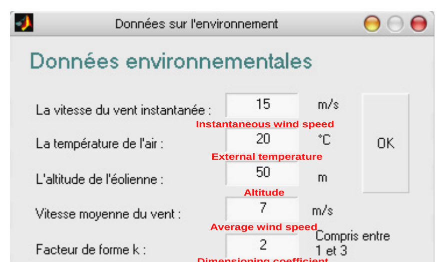


Fig. 12. Environmental data menu.

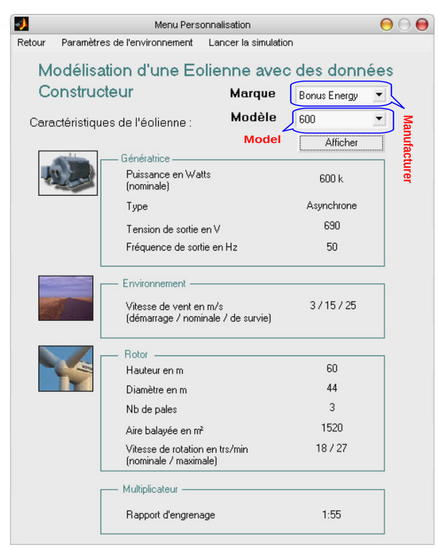


Fig. 13. The "manufacturer" menu.

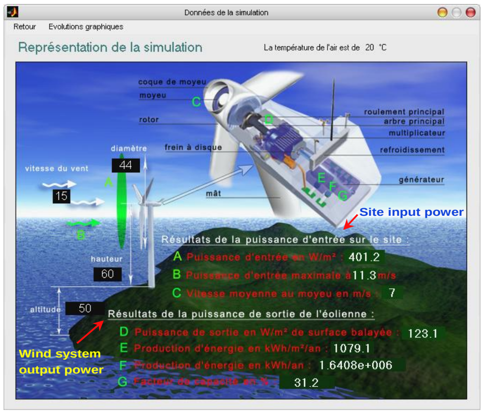


Fig. 14. Simulation window.

After simulation, the user will obtain the following information or results [2]:

– *The site input powers*: Captured power, maximum input power and the average blade rotational speed.

– *The wind turbine output powers*: Wind turbine output power, mechanical power transmitted to the generator, annual electrical power transmitted to the grid and the capacity factor.

– *The following curves*: Wind turbine power, wind power density, power density and the power coefficient.

IV. Realization of a Wind Energy System Model

The above-developed software was then used by another group of three students of the Institute second year to realize a wind energy system model that would generate (as a first model) a 12 V for domestic DC applications. For teaching and practical reasons, we have advised the students to use the customized menu for the wind system realization. The following aspects were then treated.

A. Technology and Mechanical Aspects

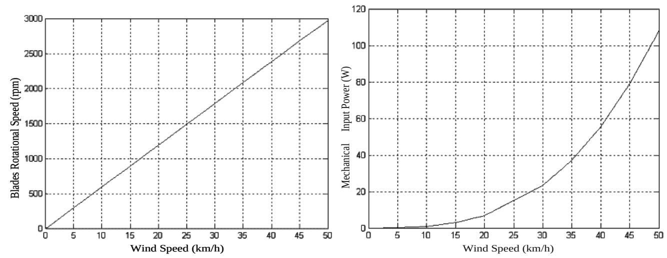
1) Technology. A horizontal-axis three-bladed wind turbine was adopted. Indeed, horizontal-axis wind turbines have the largest market share and it is also expected to dominate the development in the near future. Moreover, three-bladed wind turbines dominate the market for grid-connected, horizontal-axis wind turbines. Two-bladed wind turbines, however, have the advantage that the tower top weight is lighter and, therefore, the whole supporting structure can be built lighter, and thereby very likely cost will be lower. Three-bladed wind turbines have the advantage that the rotor moment of inertia is easier to understand and, therefore, often better to handle than the rotor moment of inertia of a two-bladed turbine. Furthermore, three-bladed wind turbines are often attributed *better* visual aesthetics and a lower noise level than two-bladed wind turbines.

The three-bladed wind turbine adopted and realized has the following characteristics (Fig. 15): *tip speed ratio* (λ = 6.5), *power coefficient* (C_p =0.25), and *diameter* (D = 0.58 m).

2) Wind System Characterization. According to the above data, two main characteristics of the wind system have been carried out and are illustrated by Fig. 16.

According to the adopted three-bladed system and to the software available coherent parameters, the wind system tower has been selected and realized by the students (Fig. 17). It has also been equipped with a system to fasten the generator.

Fig. 15. The three-bladed wind turbine adopted and realized.



(a) (b)

Fig. 16. The adopted wind turbine main characteristics: (a) Blade rotational speed versus wind speed. (b) Available input power (blades rotation) versus wind speed.

Fig. 17. The wind system tower realized by the students.

B. The Generator

For DC domestic applications, a 12 V permanent magnet DC generator has been selected (Fig. 18). This selection was based on coherent values given by the developed software.

C. The Wind System Energy Model

The realized model is illustrated by figure 19. The wind turbine is supposed to feed a DC domestic 12 V application. A series of tests in real conditions were carried out to validate the model. Indeed, as we have no experimental means to generate a 10 km/h artificial wind, the tests were carried out in a windy area (downtown Amiens, France, Fig. 20) and also near a real wind farm (Baie de Somme, Picardie in North of France) as shown in Fig. 21.

Fig. 18. The chosen generator.

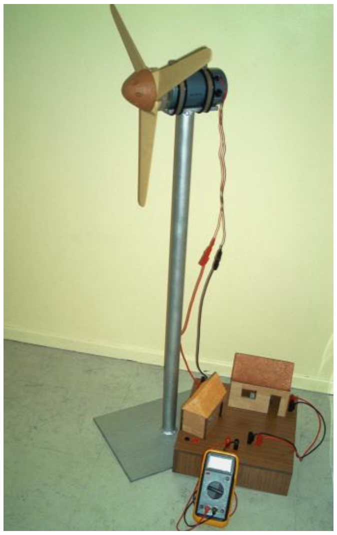


Fig. 19. The realized model.

Fig. 20. Views of the wind system experimental validations.

Fig. 21. The model operating near a real wind farm in Baie de Somme, Picardie (France).

In Fig. 20, one could not that the wind energy system was able de generate a DC voltage of 11.55 V.

V. Conclusions

In addition to the education objectives of the undergraduate student projects, an essential element was to present students attractive and exciting topics that entice them into Power Engineering. Indeed, students are positively impacted by environmental topics such as pollution prevention, pollution remediation, and natural resource utilization (renewable energies). Therefore, such motivating Power Engineering topics can push students to increase their investment for the success of the undertaken project if it includes elements of both credible analysis and experimental proofing such as design and implementation. This was the case of the wind energy system project presented in this paper: *software development*, *mechanical design*, *realization*, *experimental proofing*, etc.). Moreover, what was interesting with the proposed undergraduate student project is that it includes the fundamental material that already exists in many power engineering courses.

Undergraduate student projects were found as an excellent framework to transition from theoretical work in the classroom and experiential learning with applications of technology and design. The main objective was to bridge the gap between academic theory and real world practice. Moreover, with such kind of interdisciplinary undergraduate projects (wind energy systems), we sensitive students to the interdisciplinary of actual job market (electrical engineering, mechanical engineering, etc.). These projects also lead them to deepen knowledge and to acquire new ones.

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